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HUMAN FACTOR PROBLEMS IN ANTI-SUBMARINE WARFARE

Technical Report 9

SIGNAL DETECTION AS A FUNCTION OF INTERSIGNAL INTERVAL DURATION

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HUMAN FACTOR PROBLEMS IN ANTI-SUBMARINE WARFARE

Technical Report 9

SIGNAL DETECTION AS A FUNCTION OF INTERSIGNAL INTERVAL DURATION

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Prepared for

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SUMMARY

The purpose of this study was to determine whether the relationship between probability of signal detection and intersignal interval duration changes when the distribution of interval durations is changed.

The probability of signal detection as a function of intersignal interval duration was determined from data obtained in three studies of vigilance performance. In the first study, the distribution of intersignal intervals was positively skewed--there were many more brief intervals than long intervals. In the second and third studies, the distributions of intervals were rectangular. The intersignal intervals were identified in three ways: (1) the amount of time since the previous signal was detected, (2) the amount of time since the previous signal occurred, and (3) the amount of time since the previous signal was missed.

Within-subject analyses showed that probability of detection as a function of time since the previous signal was detected decreased when the distribution of interval durations was positively skewed and increased when the distributions were rectangular. Probability of detection as a function of time since the previous signal occurred remained the same when the distribution was skewed and increased when the distributions were rectangular. Probability of detection as a function of time since the previous signal was missed increased for both the skewed and rectangular distributions of intervals.

The results support an expectancy theory of vigilance, if theory is modified to state that expectancy (and hence probability of detection) is highest at the modal rather than the mean intersignal interval.

Supplementary analyses of data showed the following:

1. Subjects expecting long intervals tended to detect a higher percentage of signals following long intervals than they did

following short intervals; and subjects expecting short intervals tended to detect a higher percentage of signals following short intervals than following long intervals. These results were consistent with the expectancy hypothesis but were not statistically significant.

2. A comparison of performances on single-mode and dual-mode vigilance tasks showed that probability of detection on a single-mode task systematically increased as intersignal interval duration increased; but on a dual-mode task probability of detection was essentially the same for all intersignal intervals--with the exception of the mean interval at which probability of detection was highest.

3. On a dual-mode task, visual signals were equally detectable following a visual detection or an auditory detection; and auditory signals were equally detectable following an auditory detection or a visual detection. This result was taken to be possibly inconsistent with both a reinforcement and a filter theory of vigilance.

INTRODUCTION

The purpose of this study was to attempt to clarify the relationship between the probability of signal detection and the duration of the intersignal interval in a vigilance task. The results of a previous analysis of this relationship were difficult to interpret, primarily because the distribution of intersignal intervals was skewed (Harabedian, McGrath, and Buckner, 1960). In the present analysis, the distributions of intersignal intervals were rectangular so that the previous findings could be more adequately interpreted and the effect of the distributions of intervals could be evaluated.

The previous study (Harabedian, et al., 1960 - hereafter: study #1) was conducted to test predictions derived from the reinforcement and the expectancy theories of vigilance (Baker, 1959; Deese, 1955). The prediction derived from the reinforcement theory was that the probability of detection would be greatest immediately following the detection of a signal and would decrease as a function of time between signals. The prediction derived from the expectancy theory was that the probability of detection would be lowest immediately following the occurrence or detection of a signal and would increase as a function of time between signals.

The following results were obtained:

1. As the amount of time following the detection of a signal increased, the probability of detection decreased for both high and low signal rates.
2. As the amount of time following the occurrence of a signal increased, the probability of detection increased for the low signal rate and remained constant for the high signal rate.
3. As the amount of time following a missed signal increased, the probability of detection increased for both the high and low signal rates.

Thus it appeared that the relationship between the probability of detection and the duration of the intersignal interval depended upon the way the interval was identified (either the amount of time since the last signal was detected or the time since the last signal occurred or the time since the last signal was missed). The first result seemed to support the reinforcement theory, and the second result seemed to support the expectancy theory. However, the distribution of intersignal intervals was positively skewed--there were many more brief intervals than there were long intervals. Therefore, if the assumption were made that expectancy would be highest at the modal rather than the mean interval, both results would be consistent with the expectancy theory. Because of the skewed distribution of intervals, the interpretation of the findings was equivocal. The present analysis was conducted to determine whether a change in the distribution of intersignal interval durations would change the relationship between probability of signal detection and interval duration.

METHOD

The data for the present analyses came from two studies reported elsewhere: a study (hereafter: study #2) of the effects of auditory stimulation on visual vigilance performance (McGrath, 1960) and a study (hereafter: study #3) of single-mode and dual-mode monitoring (Buckner and McGrath, 1961). The vigilance tasks in these studies were the same as those in Study #1. The tasks required subjects to detect an increase in the brightness of an intermittent light or an increase in the loudness of an intermittent tone. In Studies #2 and #3 signals occurred at an average rate of 24 per hour. The durations of the intervals between signals were determined randomly, within the restriction that the minimum duration be 9 seconds. This had three effects: (1) the signals occurred at irregular intervals and presumably their time of occurrence was not predictable by the subjects, (2) the distribution of intersignal interval durations was rectangular, and (3) the different durations of intersignal intervals were equally distributed throughout all parts of the one-hour watches. The duration of intersignal intervals ranged from 9 seconds to 300 seconds. These rectangular distributions of intersignal intervals and the skewed distribution used in Study #1 are shown in Figure 1.

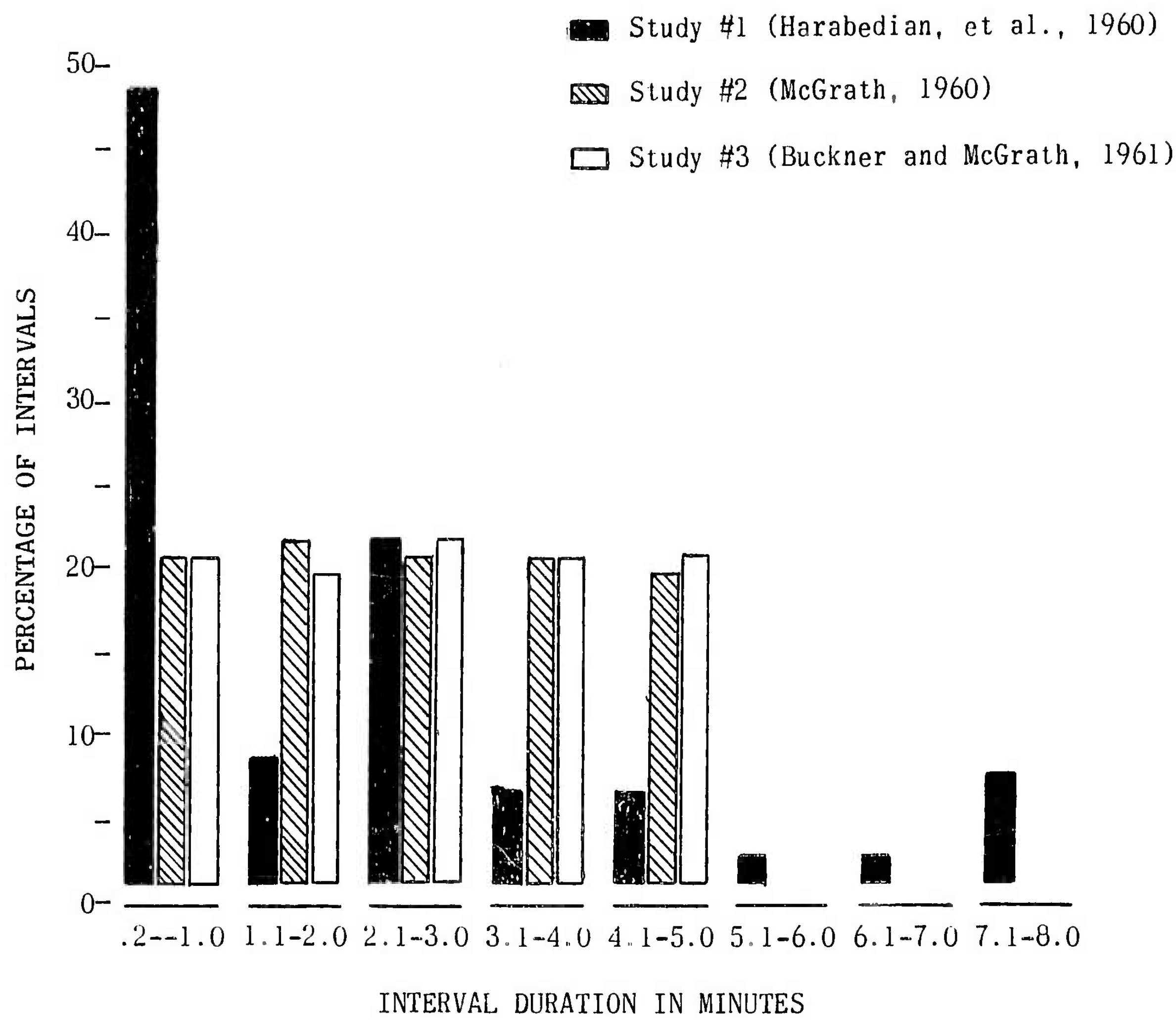

Figure 1. Distributions of intersignal interval durations used in the previous (Study #1) and present (Studies #2 and #3) analyses.

As in Study #1 probability of signal detection as a function of intersignal interval was identified in three ways:

1. Percentage of subjects detecting the signal who had detected the previous signal. (Detection of the previous signal was the interval referent.)

2. Percentage of subjects detecting the signal whether or not they had detected the previous signal. (Occurrence of the previous signal was the interval referent.)

3. Percentage of subjects detecting the signal who had not detected the previous signal. (Missing the previous signal was the interval referent.)

RESULTS

In the figures on the following pages, only the high signal rate data are reported from Study #1 because that rate (30/hour) was most similar to the rate (24/hour) used in Studies #2 and #3.

As the amount of time following the detection of a signal increased, the probability of detection decreased when the distribution of intervals was positively skewed and increased when the distribution of intervals was rectangular (Figure 2). As the amount of time following the occurrence of the signal increased, the probability of detection remained essentially unchanged when the distribution of intervals was positively skewed and increased when it was rectangular (Figure 3). As the amount of time following the missing of a signal increased, the probability of detection increased for both the positively skewed and the rectangular distributions (Figure 4). The data from Study #3 were not analyzed using a missed signal as the interval referent. Regardless of the interval referent with the rectangular distribution, the probability of detection increased as the duration of the interval increased. These results are summarized in Table I.

An analysis of variance was used to test the significance of the effects of intersignal interval duration on detection performance. Because within-subjects data had been obtained from Study #3 and only group data had been obtained from Study #2 and since the results of Studies #2 and #3 were highly similar, the analyses were performed using only the data from Study #3. The results of the analyses of variance, presented in Tables II and III, show that the mean differences

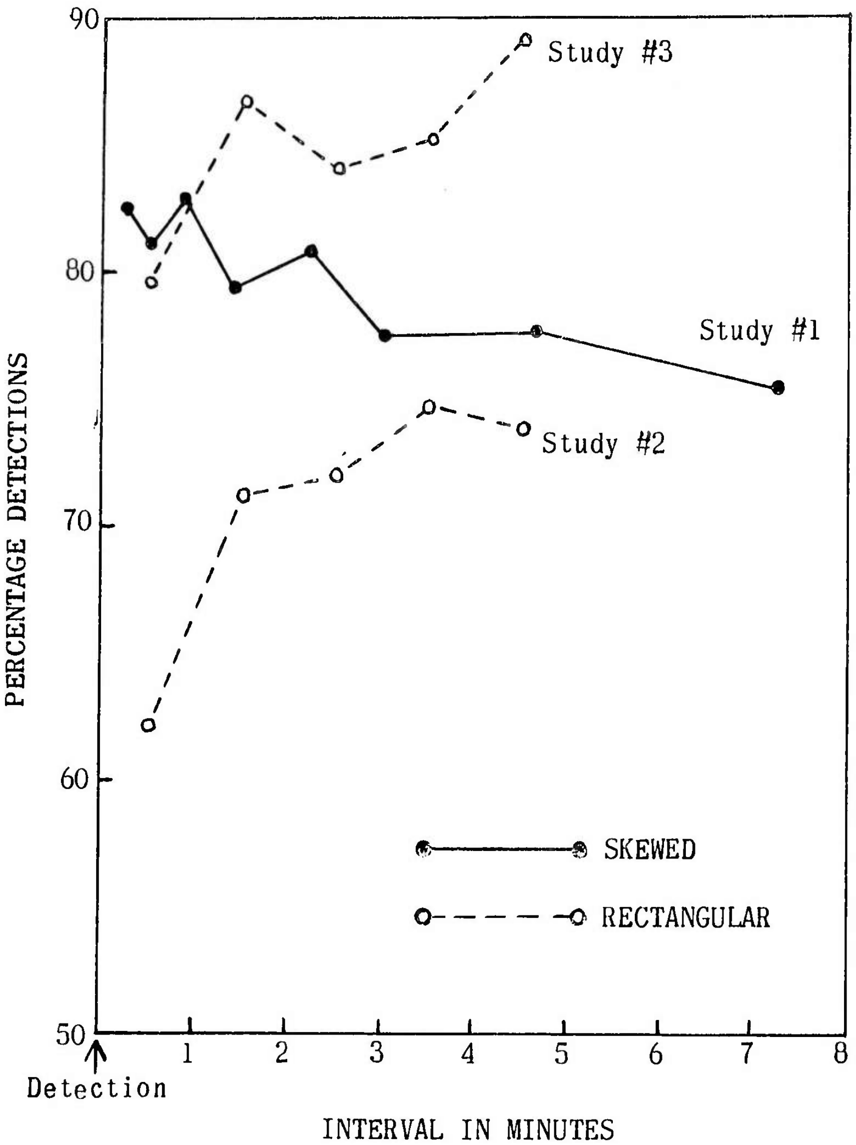

Figure 2. The percentage of subjects detecting the signal who had detected the previous signal as a function of the duration of intersignal interval.

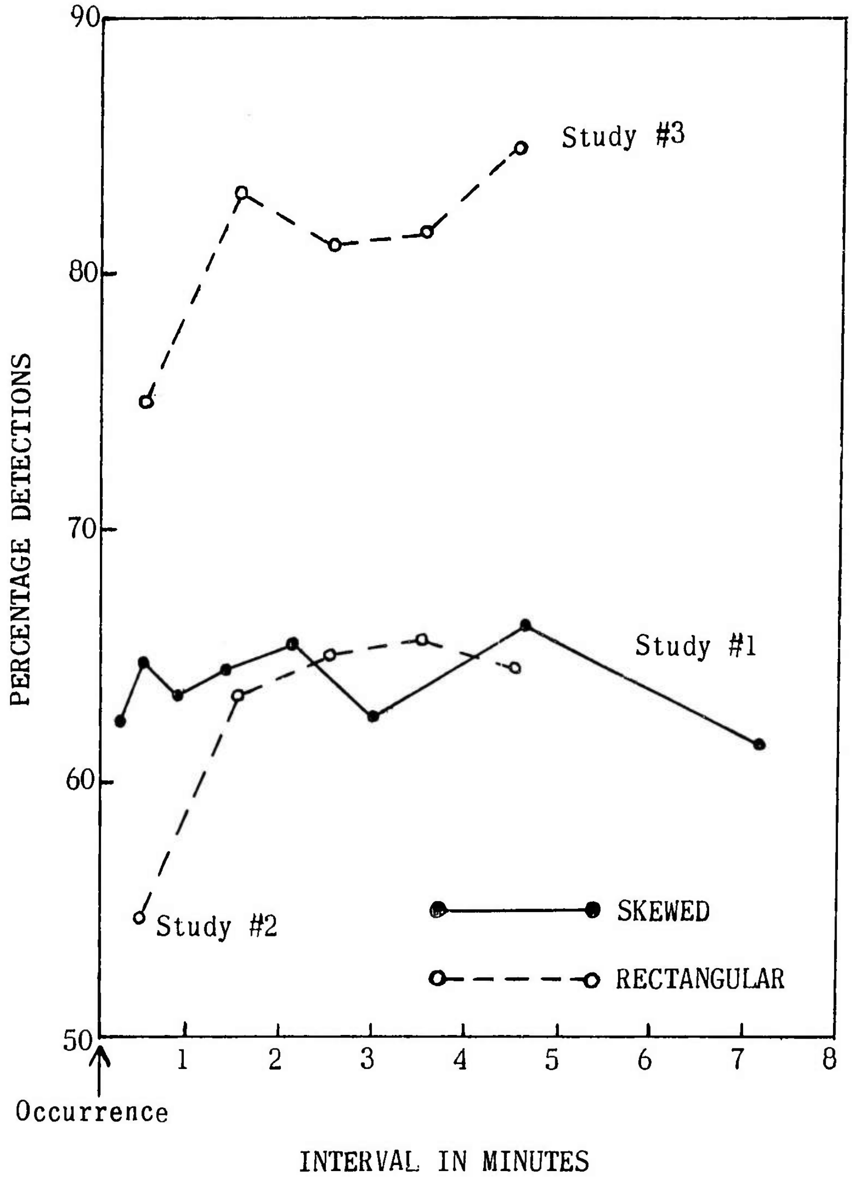

Figure 3. The percentage of subjects detecting the signal whether or not the previous signal was detected as a function of the duration of intersignal interval.

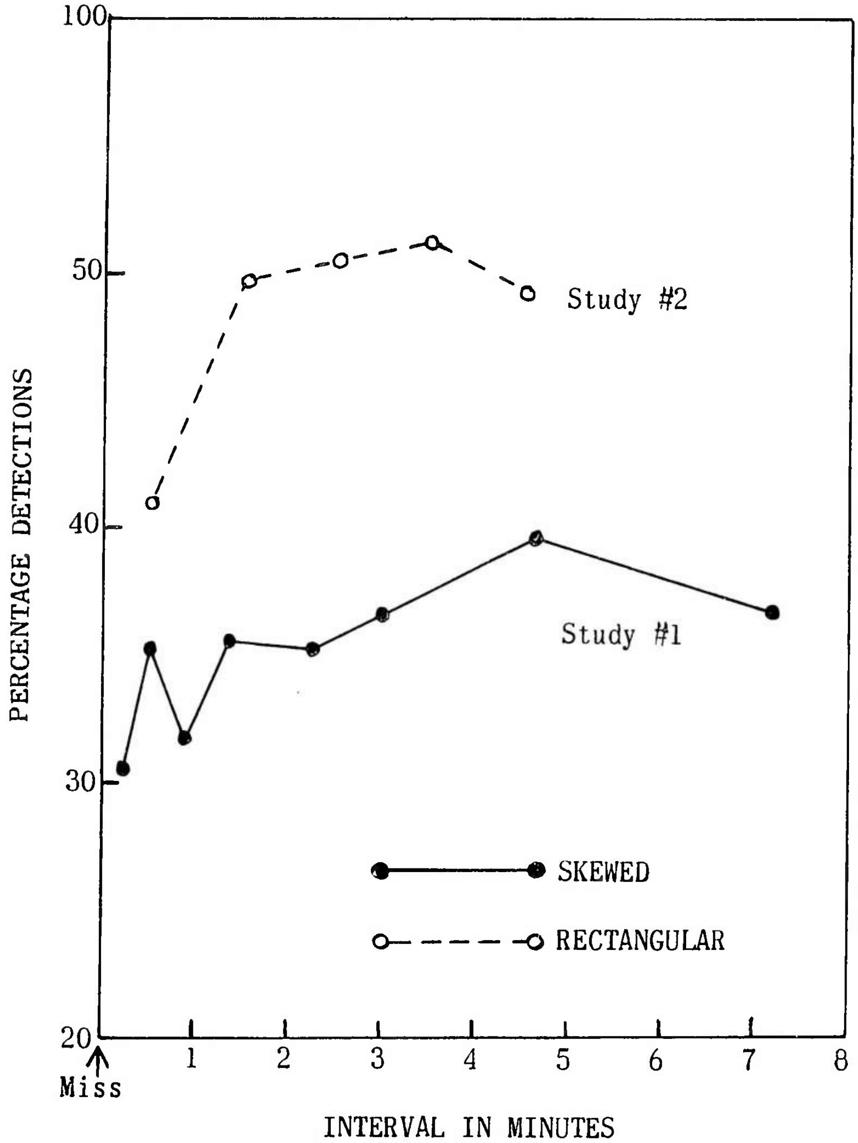

Figure 4. The percentage of subjects detecting the signal who missed the previous signal as a function of the duration of intersignal interval.

in detection performance between intervals were highly significant.

Table I

Summary of Results Shown in Figures 2, 3, and 4

Under the indicated conditions, as the duration of intersignal interval increased, probability of signal detection ____________.

Interval Referent	SKEWED DISTRIBUTION	RECTANGULAR DISTRIBUTION
DETECTION of previous signal	decreased	increased
OCCURRENCE of previous signal	remained constant	increased
MISSING of previous signal	increased	increased

Table II

Analysis of Variance of the Effects of Intersignal Interval Duration on Detection Performance (Detection as the interval referent)

SOURCE	df	Mean Square	F
Intervals	4	325	4.65*
Subjects	26	--	
Residual	104	69.9	

* $p < .005$

Table III

Analysis of Variance of the Effects of Intersignal Interval Duration on Detection Performance (Occurrence as the interval referent)

SOURCE	df	Mean Square	F
Intervals	4	406	5.97*
Subjects	26	--	
Residual	104	68	

* $p < .001$

DISCUSSION

The results of the previous study were confirmed in this analysis when a <u>missed</u> signal or the occurrence of a signal was the interval referent. The most striking result was the reversal of the relation between interval duration and probability of signal detection when <u>detection</u> of a previous signal was the interval referent. In contrast to the previous findings, in the present analysis probability of signal detection was lowest immediately following a detection. Apparently this reversal was a result of the difference in the shape of the distribution of intersignal intervals in the previous and the present studies. The distribution of intersignal intervals evidently affects the relation between probability of detection and interval duration to a greater degree when <u>detection</u> of the previous signal is the interval referent.

These results would support an expectancy hypothesis if the assumption were made that the level of expectancy (and hence the probability of signal detection) is greatest at the <u>modal</u> rather than at the mean interval duration.

At least two conclusions seem warranted: (1) the shape of the distribution of interval duration affects the relationship between the probability of signal detection and the duration of intersignal interval, especially when <u>detection</u> of the previous signal is used as a referent in identifying the interval. (2) The relationship between probability of signal detection and intersignal interval duration (<u>detection</u> as a referent) reported in the previous study now seems better explained in terms of an expectancy hypothesis.

SUPPLEMENTARY ANALYSES

At the conclusion of the experimental sessions in Study #3, the subjects were asked to estimate the average number of signals that they thought had occurred during a watch. Those who estimated that a large number of signals occurred were assumed to have expected short intersignal interval durations during the watches, and those who estimated that few signals appeared were assumed to have expected long intersignal intervals. The probability of detection as a function of the duration of the intersignal intervals was determined for the ten subjects estimating the longest intersignal intervals and the ten subjects estimating the shortest intersignal intervals (Figure 5). It can be seen that those subjects expecting long intervals detected a greater percentage of signals when the actual intersignal interval was long than when it was short, and those who estimated short intervals detected a greater percentage of signals when the actual interval was short than when it was long. However, an analysis of variance indicated that these effects were not statistically significant (Table IV). They are nevertheless in the direction that would be predicted from the expectancy hypothesis, and the results are presented here mainly because they suggest a new approach to a test of the expectancy hypothesis.

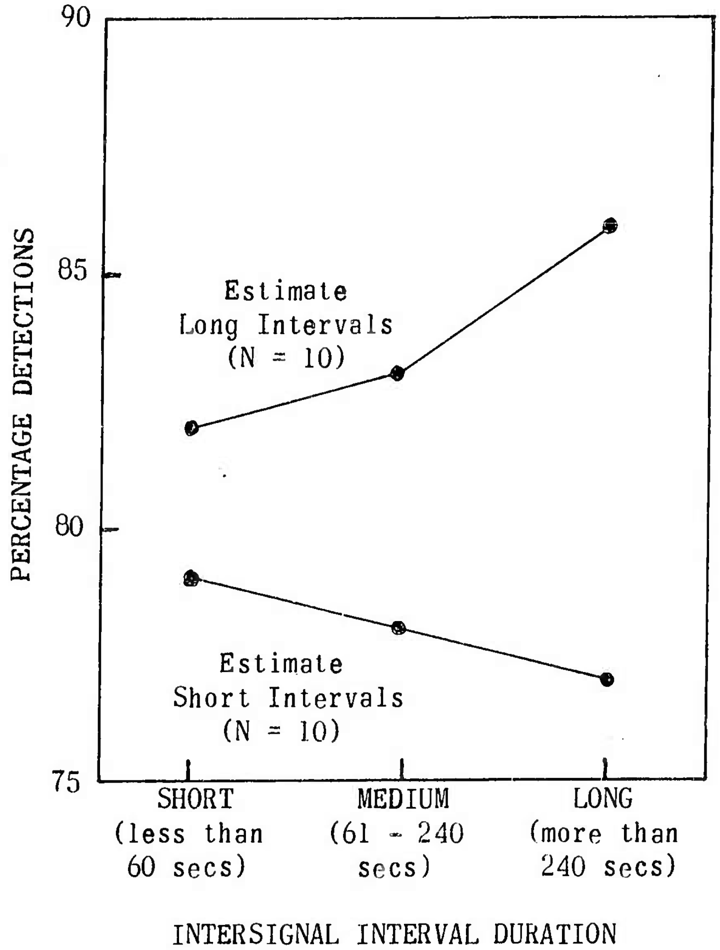

Figure 5. Percentage of signals detected after short, medium, and long intersignal intervals by 10 subjects expecting long intervals and 10 subjects expecting short intervals.

Another analysis of the data from Study #3 was performed to compare the effects of intersignal interval duration on performance on single-mode and dual-mode vigilance tasks (Figure 6). The differences between mean performance levels at the different intervals were significant for both the single-mode and the dual-mode curves (Tables II and V). The shapes of the curves, however, were quite different. On the single-mode displays, probability of detection systematically increased as the intersignal interval duration increased. But on the dual-mode display,

Table IV

Analysis of Variance of Detection Performance of Subjects Expecting Long Intervals and Subjects Expecting Short Intervals as a Function of Intersignal Interval Duration

SOURCE	df		Mean Square	F
Between Groups	1		571	1.49
Between Ss in Same Group	18		384	
Total between Ss		19		
Between Intervals	2		4	
Groups x Intervals	2		39	.51
Residual	36		77	
		40		
Total:		59		

probability of detection was essentially the same for all intersignal intervals--with the exception of the mean interval at which probability of detection was highest. These results suggest, if they are to be explained in terms of expectancy, that the expectancy function is different on simple tasks and complex tasks. On a complex task, there seems to be an increase in expectancy at the mean interval only as opposed to the continuous rise in expectancy on a simple vigilance task.

One more analysis was performed using the data from Study #3 to see whether visual and auditory signals were more likely to be detected when they followed detected signals on the same mode than when they followed detected signals on a different mode. One might expect from a reinforcement theory that when a signal is detected on a dual-mode task the subject would be more likely to continue attending to the display upon which he detected the signal (i.e., received reinforcement)

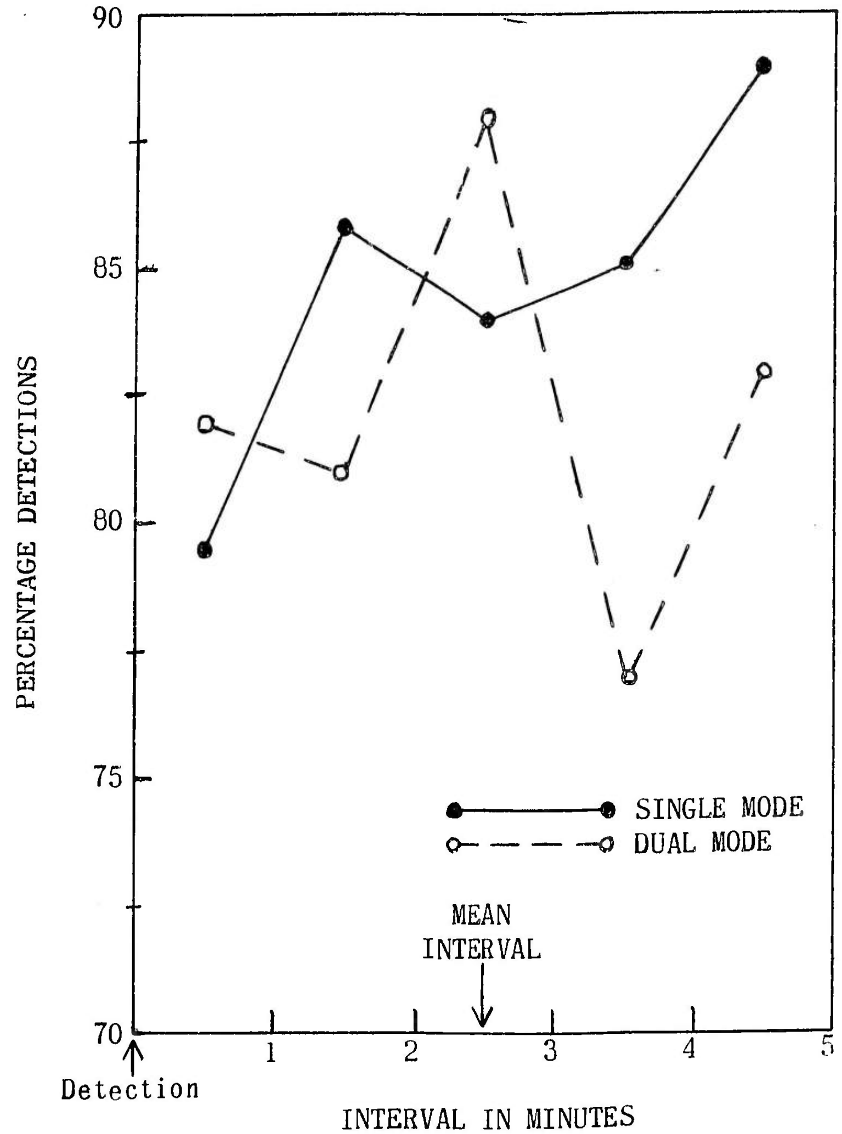

Figure 6. Percentage of signals detected as a function of intersignal interval duration for visual and auditory vigilance tasks performed separately (single-mode) and concurrently (dual-mode).

than to the display upon which no signal appeared. The predictions from this point of view would be that auditory signals would be more likely to be detected following an auditory detection than following a visual detection, and that visual signals would be more likely to be detected following visual detections than following auditory detections. But one might predict from Broadbent's (1958) filter theory that the subject would be likely to shift channels after making a detection

Table V

Analysis of Variance of the Effects of Intersignal Interval Duration on Detection Performance on a Dual-Mode Vigilance Task (Detection as the interval referent)

SOURCE	df	Mean Square	F
Intervals	4	382.5	2.66*
Subjects	26	386.6	
Residual	104	143.7	

* $p < .05$

and that signals appearing on the opposite mode would be more likely to be detected.

The results shown in Table VI indicated that neither hypothesis was supported. Auditory signals were equally detectable whether they followed an auditory or a visual detection. And visual signals were equally detectable following a visual or an auditory detection. This was true for all durations of intersignal interval.

Table VI

Probability of Detecting Auditory and Visual Signals Following Detections on the Same or Different Modes

Following the detection of:	Probability of Detecting: A Visual Signal	Probability of Detecting: An Auditory Signal
A Visual Signal	.74	.91
An Auditory Signal	.75	.93

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